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Electrical Contact Response in a Vibratory Environment

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The reaction of electrical contacts to vibration fields has taken on added importance with the use of relays and other switching devices in vehicles which inherently produce, or operate in, a vibratory environment. The missile has generated the greatest interest in this area, not only because of the presence of a hostile vibratory environment, but also because of the requirement for a high degree of circuit reliability.

The proper design of switching devices to be used in a vibratory environment requires knowledge of the mechanical reaction of the contacts to the environment. This knowledge, coupled with other design considerations, should enable the designer to avoid or control reactions which would be detrimental. It appears that very little has been done in the past to analyze the vibration effect from a basic mechanical standpoint. Instead, existing configurations have been altered through experimental trial and error for use in a vibratory environment. This approach has met with varying degrees of success. In view of this, basic studies of the mechanical reaction of contacts to a vibratory environment are needed.

One problem area associated with contact vibration is that of inadvertent separation of contacts which are held in the closed position by a set force. The vibratory environment generates dynamic forces which overcome the preload force holding the contacts together. This results in unintentional separation which may introduce a spurious signal into the system.

From a purely mechanical standpoint, the problem is one of controlling the vibration response of the contacts so that they will not separate when subjected to a vibratory excitation. The allowable response for non-separation may be expected to vary from one contact configuration to another, but be limited for all configurations. However, every mechanical system possesses at least one inherent frequency such that, in the absence of damping, excitation at that frequency will theoretically result in unbounded amplitude. Consequently, control of the contact-response amplitude over an unlimited frequency range of excitation can be accomplished only through energy dissipation with some type of damping.

Since mechanical damping is dependent upon either displacement or velocity, there

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must be an allowable response amplitude of the contacts without separation if separation is to be prevented in a vibration environment of unlimited frequency range. The problem then becomes one of determining the nonseparation amplitude for a given configuration so that the contact response can be held to a lower amplitude through energy dissipation.

The author has completed an investigation to determine the allowable nonseparation response amplitude of a nonlinear contact system in which the vibration environment was taken as steady state sinusoidal.(1) The investigation included both theoretical and experimental work. The nonlinearity entered the problem through representation of the elasticity of one contact as being of the Duffing hardening type.(2) A wide variety of possible contact configurations was represented by considering a lumped parameter system in which the system parameters were allowed to take on arbitrary values. Although aimed primarily toward electrical contacts, the results of the investigation are equally applicable to any system which can be represented as a two-mass, two-spring, lumped parameter system.

From an intuitive standpoint, it might be assumed that the allowable nonseparation response amplitude of a set of contacts would depend upon the frequency of the vibratory excitation. However, for the conditions investigated, this is not true. Instead, the allowable response amplitude was found to be solely dependent upon contact configuration and preload.

It was also found that the commonly used configuration of one rigid and one flexible contact permits no allowable nonseparation response amplitude so that there is no way of preventing separation over an unlimited frequency range of excitation. On the other hand, a linear contact configuration where the two contacts have the same natural frequency theoretically permits an unbounded nonseparation response amplitude. Although such a condition would be impossible to achieve in practice, an approximation would provide a sufficiently large nonseparation response so that effective damping might be introduced.

The presence of the nonlinearity of the one elastic restoring element not only complicated the problem immeasurably but, in general, decreased the allowable nonseparation response amplitude. A combination of preload and nonlinearity results in a system which has nonsymmetrical restoring forces about the static equilibrium position. Consequently,

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Editor

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the contact response was found to be essentially a biased sinusoid about the static equilibrium position where the biasing was related to the response amplitude through a complex relationship involving system parameters and preload. There were, however, both even and odd higher harmonics present in the response to a small degree. The even harmonics were the results of the nonsymmetry and are predictable theoretically.(3) Since the effects of the nonlinearity were found to be entirely detrimental, it appears that the relay designer should attempt to design a configuration where the elasticity of the contacts is purely linear.

One interesting sidelight of the investigation concerns the recording of the nonlinear jump phenomenon in the time domain. The existence of this phenomenon is well known and theoretically predictable in the frequency domain. However, it appears that little is known about the mechanism of the jump as revealed by the time-domain response recordings. These could provide the basis for a complete analysis of the jump phenomenon which would be a significant contribution to the nonlinear field. ★

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THE CONVERSION OF A POWER SERIES TO A CONTINUED FRACTION or HOW TO GET SOMETHING FOR (PRACTICALLY) NOTHING

H. E. FETTIS, Mathematics Research Laboratory, ARL

Probably the most common way of computing both elementary and higher transcendental functions is by means of power series. The function $\tan^{-1}(x)$, for example, has the power-series representation

$$\tan^{-1}x = x - \frac{x^3}{3} + \frac{x^5}{5} - \ldots + .$$

Unfortunately, such representations are in general very limited in their usefulness, being good only for a restricted range of x. In fact, the above series does not even converge when $x > 1$, and for values near to 1 is so slowly convergent as to be virtually useless. Frequently, use may be made of analytical properties of a function to avoid this difficulty. As an example in the present case, certain additional formulae may be invoked to allow the maximum value of x to be smaller than unity. However, many cases exist where such devices are not applicable. For example, the "error function" which is important in statistical as well as in many physical problems, namely

$$\mathrm{Erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt .$$

has the power-series representation

$$\frac{\sqrt{\pi}}{2} \mathrm{Erf}(x) = x - \frac{x^3}{3 \cdot 1!} + \frac{x^5}{5 \cdot 2!} - \ldots +$$

and even though this series converges for all finite values, it does not give satisfactory results for large x, since many terms are required, and there is a great loss of accuracy due to the fact that the final result depends on the differences of large numbers. For

large values of x, it would be ideal to have a power series in the variable 1/x. Such a representation does exist, as we can formally obtain the expression:

$$\mathrm{Erf}(x) = 1 - \frac{e^{-x^2}}{x\sqrt{\pi}}\left[1 - \frac{2!}{(2x)^2} + \frac{4!}{2!(2x)^4} - \frac{6!}{3!(2x)^6} + \ldots + \right],$$

but it is soon found that the series is divergent for all finite values of x. Such a divergent representation is called an asymptotic series, and it can be shown that accurate results can only be obtained if x is sufficiently large, regardless of the number of terms used. In fact, with too many terms, we may even get a less accurate result than with a lesser number. For this reason, the utility of asymptotic series is limited in computation.

A third type of representation which we will now discuss turns out, in many cases, to be the most useful of all, namely the so-called "continued fraction." It is an expression which is obtained by writing first the quotient of two numbers, say

$$a_0/b_0,$$

then adding to the denominator a new quotient a_1/b_1, adding a similar quotient to the denominator of this one, etc. In final form, it looks like

$$\cfrac{a_0}{b_0 + \cfrac{a_1}{b_1 + \cfrac{a_2}{b_2 + \cdots +}}}.$$

It is clear that, if all the denominators are larger than the corresponding numerators, the result which is obtained by taking (say) n terms will not differ too much from that obtained with (n + 1) terms. When this happens, the continued fraction is said to converge. Actually, the question of convergence involves much more, but the general idea is conveyed by this line of thought.

Because of their relatively simple structure, continued fractions are very easy to evaluate on a digital computer (much more so even than series). But they have a still more important property; they are usually more rapidly convergent than the corresponding series, and they will frequently even converge in cases where the series representation does not. For example, the continued fraction representation for the inverse tangent, namely

$$\tan^{-1}x = \cfrac{x}{1 + \cfrac{x^2}{3 + \cfrac{(2x)^2}{5 + \cfrac{(3x)^2}{7 + \cdots +}}}}.$$

not only converges more rapidly than the power series when $x<1$, but even converges for $x>1$ where the power series diverges. For these reasons, it would be of great value to be able to take a given power series and derive from it an equivalent continued fraction. This can in fact be done using nothing more than elementary algebraic operations. Suppose, for example, that we were to start with the series for the inverse tangent in the form

$$\frac{1}{x}\tan^{-1}x = 1 - \frac{x^2}{3} + \frac{x^4}{5} - \frac{x^6}{7} + \ldots + .$$

We wish to derive from this an equivalent continued fraction of the form

$$\cfrac{a_1}{b_1 + \cfrac{a_2x^2}{b_2 + \cfrac{a_3x^2}{b_3 + \cdots +}}}.$$

It is at once evident that, if both representations are terminated after n terms, the number of undetermined coefficients will exceed the number of relations to be satisfied. However, this additional number will allow us to obtain rational expressions for the a's and b's. For the sake of simplicity, we will

limit ourselves to four terms. By setting $x = o$, it is clear that we must have

$$a_1 / b_1 = 1$$

so that it will suffice to take

$$a_1 = 1$$

$$b_1 = 1.$$

This gives us

$$\cfrac{1}{1 + \cfrac{a_2 x^2}{b_2 + \cfrac{a_3 x^2}{b_3 + \cfrac{a_4 x^2}{b_4}}}} = 1 - \frac{x^2}{3} + \frac{x^4}{5} - \frac{x^6}{7}.$$

Inverting and subtracting 1 from both sides of the last equation gives

$$\cfrac{a_2 x^2}{b_2 + \cfrac{a_3 x^2}{b_3 + \cfrac{a_4 x^2}{b_4}}} = \frac{\frac{x^2}{3} - \frac{x^4}{5} + \frac{x^6}{7}}{1 - \frac{x^2}{3} + \frac{x^4}{5} - \frac{x^6}{7}}$$

We may now divide both sides by x^2 and get

$$\cfrac{a_2}{b_2 + \cfrac{a_3 x^2}{b_3 + \cfrac{a_4 x^2}{b_4}}} = \frac{\frac{1}{3} - \frac{x^2}{5} + \frac{x^4}{7}}{1 - \frac{x^3}{3} + \frac{x^4}{5} - \frac{x^6}{7}}$$

which shows by setting $x = o$ that

$$\frac{a_2}{b_2} = 1/3.$$

Hence, we may take

$$a_2 = 1$$

$$b_2 = 3.$$

Substituting these values and repeating the previous steps yields

$$\cfrac{a_3}{b_3 + \cfrac{a_4 x^2}{b_4}} = \frac{\frac{4}{5} - \frac{24}{35} x^2}{1 - \frac{3}{5} x^2 + \ldots}$$

Hence

$$a_3 = 4$$

$$b_3 = 5$$

and

$$\frac{a_4}{b_4} = \frac{9/35}{\frac{1}{5} - \frac{6}{35} x^2}$$

or

$$a_4 = 9$$

$$b_4 = 7.$$

It will be observed that, as the process continues, higher-order terms in the denominators may be successively dropped as they do not contribute to the values of the coefficients which are being calculated. We have thus arrived at the first four terms of the continued fraction for $\tan^{-1}(x)$:

$$\tan^{-1} x \cong \cfrac{x}{1 + \cfrac{x^2}{3 + \cfrac{4x^2}{5 + \cfrac{9x^2}{7.}}}}$$

On a high-speed computer, many terms of the continued fraction may be obtained from the known terms of a given power series, and thus the utility of power-series representa-

tions of many functions may be greatly increased. The transformation may even be applied to asymptotic representations such as the one discussed earlier for the error function. In such cases, however, care must be exercised, since the asymptotic representation may not be unique. It is interesting to compare the results obtained from the power series with those obtained from the corresponding continued fraction with various numbers of terms. For $x = 1$, we get the following results:

No. of Terms:	Power Series:	Continued Fraction:
4	.7238	.7843
5	.8349	.7856
6	.7440	.7854

The correct value is $\pi/4 \cong .785398---$. The continued fraction with six terms is already accurate to four figures, while the series has not yet attained two correct ones. In fact, to obtain four correct decimal places from the power series, we would need over a thousand terms. ★

SCIENTIFIC NOTES

Deep Space Rocket Experiment: On 30 March 1965, the Air Force Cambridge Research Laboratories launched a four-stage, Blue Scout Jr. research rocket 7,740 miles into space. Launched from Cape Kennedy, the vehicle carried a 46.5-pound radiation experiment designed by Ludwig Katz of AFCRL. Experimental objectives were to measure the energy spectrum and pitch angle distribution of trapped charged particles through a vertical profile of the earth's radiation belt from about 1,000 miles to a peak altitude of 7,740 miles. During the 3-hour flight, the vehicle carried its pay load through the heart of the inner radiation region near the geomagnetic equator. Three sensing systems were aboard: an electrostatic analyzer, an electron spectrometer, and a proton spectrometer. The rocket reentered the atmosphere and disintegrated over South Africa. (Space Physics Laboratory, AFCRL)

ARCAS Rocket Launches: Eighteen ARCAS rockets were launched successfully by AFCRL within a 6-hour period on 6 March 1965 from the White Sands Missile Range in New Mexico. The high-altitude rocket soundings were conducted to study wind structures at altitudes between 100,000 and 220,000 feet. At these altitudes, the wind flows in an undulating manner. This wave-like motion is believed to be caused by wind moving over mountain ranges below. From these investigations, AFCRL scientists hope to learn more about this phenomenon. The 18 rockets were launched in pairs at 30-minute to 1-hour intervals. The rockets in each of the 9 pairs were launched on slightly divergent paths. At peak altitude, their separation ranged from 5 to 31 miles. This separation permitted measurements to be made of different vertical cross sections of the wave. Each of the ARCAS rockets carried an inflatable balloon called the ROBIN. The 1-meter-diameter balloons carried internal corner reflectors for radar tracking. The spheres, which were inflated above 220,000 feet, were tracked by 4 radars, 2 on each sphere. By tracking the balloon during its free fall, wind, atmospheric density, temperature and pressure can be derived. (Aerospace Instrumentation Laboratory, AFCRL)

NIRO Sounding Rocket Fired: On 12 April 1965, a Niro (Nike-Iroquois) sounding rocket was fired from the Eglin Gulf Test Range. Purpose of the flight was to test the Niro system, and also flight test a diagnostic pay load. This was the second flight of this new vehicle, and was a complete success. The first Nike-Iroquois was successfully flown on 27 November 1964. The Niro, with a gross pay load of 131 pounds, reached a zenith of about 93 statute miles. Test data, during both ascent and descent, was telemetered to ground receiving stations. The nose cone was not recovered. AFCRL project scientist was Charles P. Hoult. (Aerospace Instrumentation Laboratory, AFCRL) ★

MECHANICAL ENGINES .....of NATURE

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Motility is one of the most commonplace and prosaic properties of the animal kingdom. It is manifest in a thousand forms, from the random movements of microscopic organisms to the beautifully coordinated and complex artistry of the trained gymnast. Every living creature depends on it to capture its food, to escape its enemies and to perform the innumerable tasks of its daily existence. Yet this basic process remains a deep-seated riddle that has eluded the best scientific minds for centuries.

Obviously, motility is a form of mechanical work resulting from the contraction and relaxation of specialized tissues. Obviously, too, the ultimate source of this energy must be chemical, derived from the food consumed. The mystery of the process is inherent in the conversion of chemical to mechanical energy. After the classic experiments of Galvani and Volta, early physiologists were convinced that muscular contraction resulted from the transformation of "animal electricity" into mechanical performance. As thermodynamic theory became firmly established in the nineteenth century, many scientists were persuaded to believe that muscle was a type of thermal engine. Heat was believed to be the intermediate link, coupling the chemical energy in the muscle to the mechanical energy produced by it. Only in the last generation has the notion grown that chemical energy can be transduced directly into mechanical energy without prior transformation into either electricity or heat.

Among the pioneers, and perhaps the most persuasive exponent, of this concept of "mechanochemical" transformation has been Prof. A. Katchalski of the Weizmann Institute of Science in Rehovoth, Israel. Almost 20 years ago, he demonstrated that large molecular compounds can convert chemical energy directly into mechanical work without any change of temperature. In a recent study under AFOSR sponsorship, he has expanded his early work considerably, and has developed some general theoretical considerations valid for any contractile system. Although he and his colleagues have used a variety of macromolecules as contractile substances, Katchalski has found collagen strands to be the most useful for his present investigations. These are natural fibers similar to the sutures employed by surgeons in closing a wound. Their fibers of this type (0.03 mm) will contract markedly and rapidly when exposed to a solution of lithium bromide. On washing away the solution with water, the fiber quickly resumes its original shape. This process is reversible and reproducible. Thus, a cyclic contraction and relaxation can be repeatedly induced by adding and removing LiBr. To demonstrate this, Katchalski has constructed a simple "machine" utilizing such a collagen strand. When LiBr is admitted to a chamber containing the collagen, a marked contraction is induced, moving a weight and opening a valve which allows water to enter. The water in turn washes away the LiBr and causes the fiber to relax. The weight retur . to its original position and a second valve is opened filling the chamber with LiBr. The cycle repeats itself indefinitely in this manner. A modification of this machine utilizes a battery of contractile collagen fibers. Upon contraction, the fibers can raise a one-kilogram weight to a height of 10 cm.

Although the mechanism of this contraction is still imperfectly known, the general outline is gradually emerging. The dimensions and shape of the macromolecular chains seem to be controlled by the electrostatic field created by the charged groups on the molecule. The addition of a strong electrolyte, such as LiBr, alters this electrostatic field and produces changes in shape which are reflected as mechanical forces. Removal of these disturbing influences, by flushing with water, restores the original

Col. Chinn was on active duty at AFOSR when he wrote this article.

electrostatic field and molecular shape. In this way, a reversible, cyclic process is generated, producing a novel engine.

These simple mechanochemical machines may well be the precursors of efficient, practical engines with industrial utility. To the biologist, however, any practical application of this work is merely incidental to the exciting insights it provides into the basic processes of contractile tissue. ★

A NEW METHOD OF ACCELERATING FLOWS FOR HYPERSONIC WIND TUNNELS

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The shock tunnel has rapidly developed into an effective hypersonic research tool. The problem of its future growth potential is currently being investigated at the Cornell Aeronautical Laboratory under ARL sponsorship (Contract AF 33(657)-8860) by A. Hertzberg and J. G. Hall. In particular, one question that has been asked is, "How high a velocity can the shock tunnel reach and have a flow which will truly simulate re-entry flight?"

At the present time, shock tunnels are capable of velocities up to about 18,000 ft/sec (8,500° K plenum temperature). (1) Beyond this velocity range, direct evolutionary modifications should take the shock tunnel into the orbital velocity range (about 25,000 - 27,000 ft/sec.). However, with the expansion of programs involving re-entry orbits from moon and planetary flights, superorbital velocity requirements (50,000 ft/sec) will soon be upon us. Indeed, this problem is with us already since the research for these missions should be performed now.

In carrying out the study of velocities achievable in the shock tunnel, the driver itself was first examined. It was felt that drivers would not pose a barrier, though the demands on technology could be severe. (2) A far more severe problem proved to be the question of nozzle nonequilibrium. This question has been under study in connection with shock-tunnel development at Cornell Aeronautical Laboratory for a number of years. (3) (4) (5) Under their present contract, comprehensive calculations involving real air chemistry were carried out for future possible nozzle configurations. (6) The results indicated that it is far beyond present capability to build a nozzle which would truly expand air at very high enthalpy. Instead of air, only frozen fragments would be found in the nozzle after the air had been thoroughly dissociated, ionized, and contaminated with the oxides of nitrogen from the plenum. Hence, to take the shock tunnel into the superorbital velocity region, a new method of flow acceleration is needed which will reduce the amount of dissociation and ionization during heating, and hence reduce the amount of chemical freezing in the nozzle.

Under this program, a method was found which offers great promise. It will be called, for the purpose of this article, the "focused isentropic compression wave." This new method is based on the use of a controlled driver to focus an isentropic compression wave at the end of a shock tube so that all the air in the shock tube has been processed by a compression fan (Fig. 1). Since the focus is at the end of the shock tube, all the air in the shock tube is accelerated to a higher limiting flow Mach number than the Mach number behind a shock wave in the conventional shock tube. For example, for an ideal diatomic gas, the limiting Mach number in a conventional shock tube is only 1.89, while the limiting Mach number for a focused isentropic compression wave is equal to 5. The higher Mach number is due to the more efficient accelerating process for the isentropic compression. The heating action of the isentropic wave is less than that for the shock wave and consequently we find, on comparison with similar expansion flows obtained from a shock tunnel,

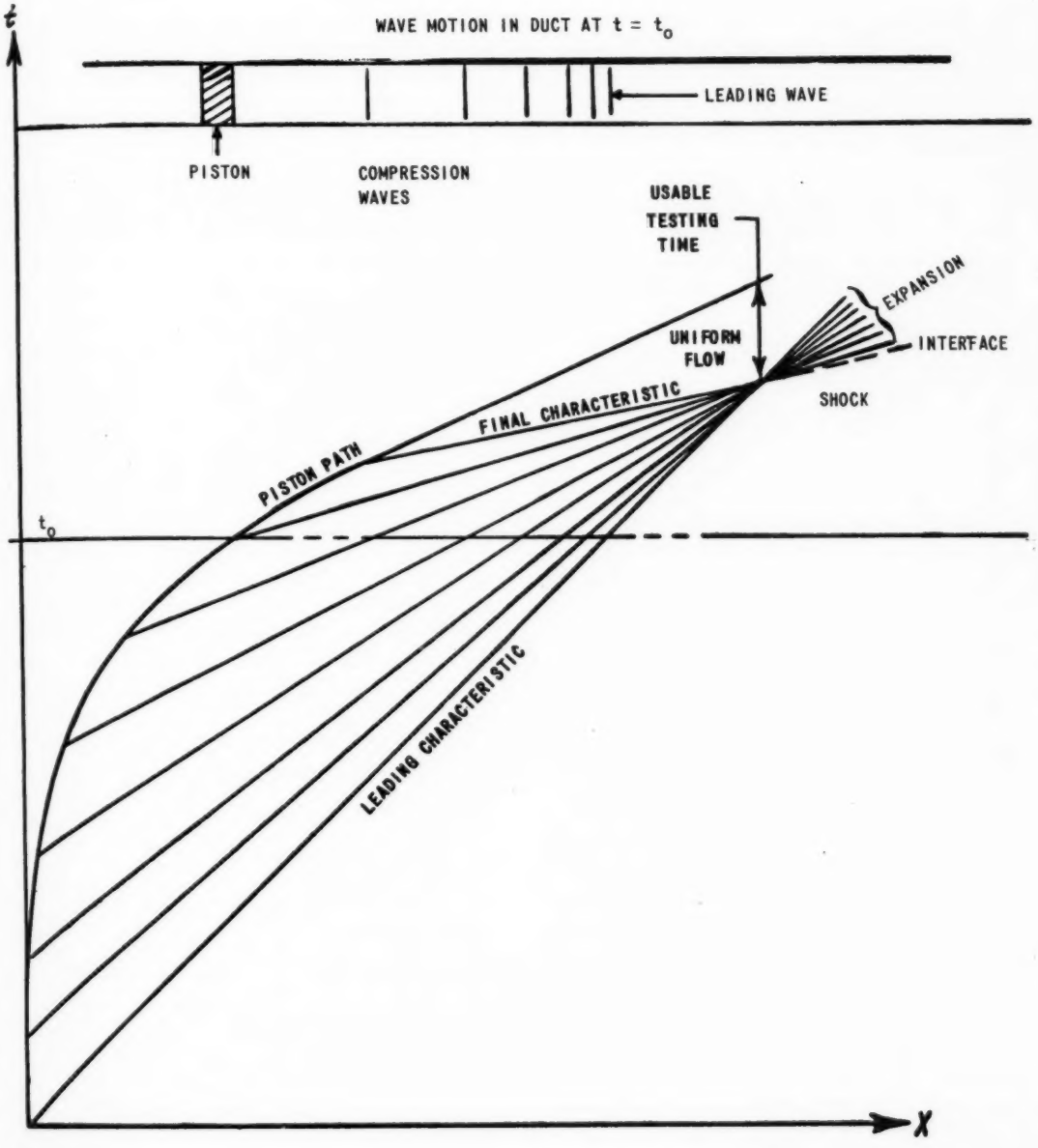

FIG. 1 Schematic wave diagram of centered compression fan

a reduced degree of freezing in the nozzle (Fig. 2). This aspect of the isentropic compression tube was found most attractive and, after comparison with other methods of flow acceleration, was felt to warrant further study.

The greatest difficulty encountered is the great length required for a reasonable period of steady flow. For example, it is conventional to think that a shock tube about 20 ft. long will produce several milliseconds of reasonably good flow for tailored-interface opera-

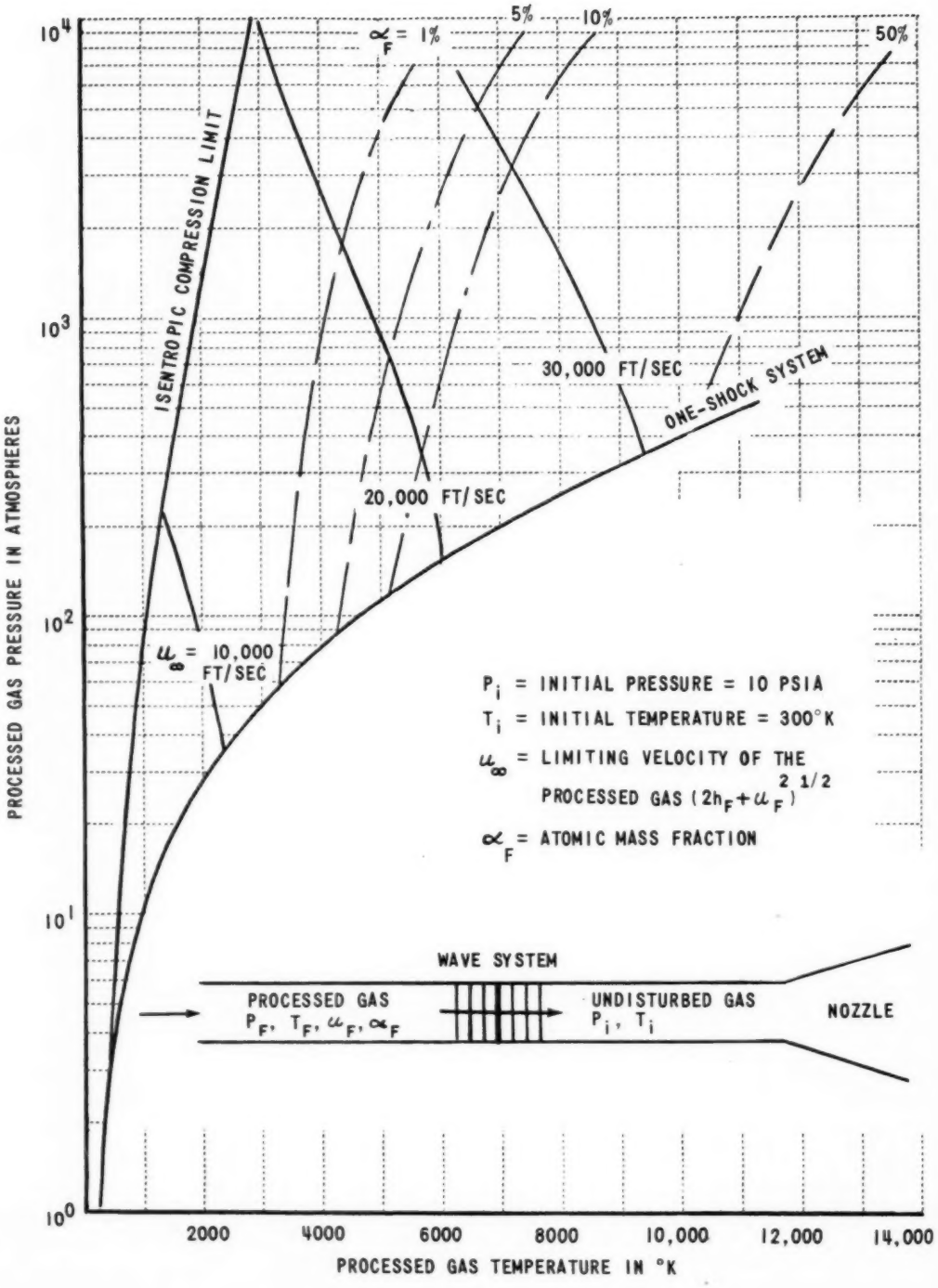

FIG. 2 Effect of wave configuration on the dissociation level of equilibrium air

tion. To obtain the same testing time with the same flow conditions for the isentropic compression case, a tube many thousands of feet long would be needed due to the much lower initial, undisturbed density which is required because of the increased efficiency of the compression process.

However, since the compression is isentropic, it was realized that manipulations of the tube area might be performed and the length of the tube greatly reduced without affecting the final performance. Calculations showed that, by focusing an isentropic compression wave through a sudden reduction in area, the same final result could be obtained with a new piston motion. These calculations were carried out by working the focused-wave problem backwards, i.e., starting from the focal point and working back through the area contraction to the required piston motion.

A second and important effect was immediately observed in the wave diagram. This leads to the possibility of velocity amplification. A close examination of the piston velocities indicated that the motion of the piston in the large diameter tube, as shown in Fig. 3, involved velocities which would be relatively low. However, the piston must be very suddenly accelerated at the contraction to sweep the entire mass of flow out of the tube without affecting the testing time. It was observed that, if the piston is halted at the contraction point, much of the air would be accelerated to a large multiple of the velocity of the piston before the expansion fan could catch it. Indeed, the maximum velocity imparted by the piston was much amplified, and velocity-amplification ratios better than 10 appear to be feasible. This result was exciting, and is stimulating further studies and detailed analysis of this type of flow acceleration.

It might be asked why effects like this have not been observed in ballistic rifles and ballistic piston-type wind tunnels. By examining the motion of the piston or interface as calculated on the wave diagram, it can be seen that the pressure history of the gas driving the piston is relatively complex, and far from that which is normally found in these types of accelerators. Currently, methods of producing the type of piston motion required are under examination, and it appears that by relatively sophisticated means the required effective motion of such a piston can be duplicated.

To summarize, the study of a method of flow acceleration which would suppress the problem of nozzle dissociation in a shock tunnel has led to the development of a new concept in flow acceleration with the possibility of velocity amplification. It is now possible to give serious consideration to shock tunnels which will duplicate air flows found in re-entry up to velocities perhaps as high as 50,000 ft/sec. The method has involved the use of an isentropic compression wave focused through an area contraction. This focusing process prescribes a specific piston path which must be duplicated inside the laboratory. Currently, such a possibility is actively being studied, and it is hoped that, in the near future, experimental verification of that possibility will be forthcoming. ★

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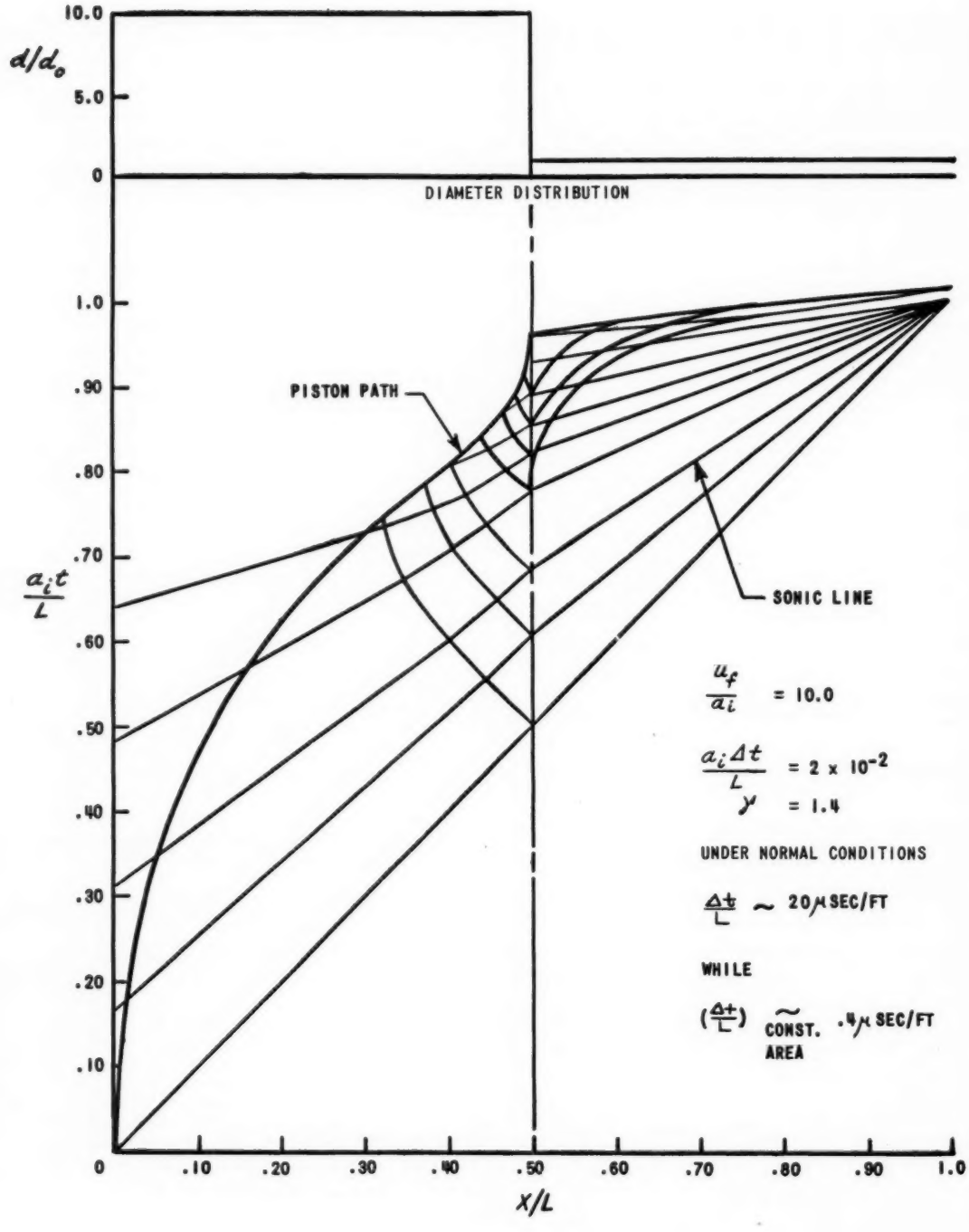


FIG. 3 Wave diagram for a centered compression wave in a duct with a discontinuous contraction

AFCRL EXPERIMENTS ACCOMPANY SNAP-10A

UPPER ATMOSPHERE PHYSICS AND SPACE PHYSICS LABORATORIES, AFCRL

The SNAP-10A nuclear-power generator, placed in orbit 3 April 1965 aboard an Air Force satellite, was accompanied by several experimental packages designed by AFCRL scientists. These scientists were: Miss Rita Sagalyn, Mr. James Ulwick, Mr. Joseph McIsaac and Dr. Robert Soberman.

The AFCRL experiments draw their power from the SNAP-10A, and are designed to measure ion-electron densities, energy distributions of these charged particles, latitude and diurnal variations of the charged particles, and the flux of micrometeorites.

The satellite, launched from Vandenberg AFB, California, was placed in a 700-mile circular polar orbit. The reactor was designed to operate for one year. Its 500-watt output is produced by the heat of nuclear fission which is converted to electricity directly by thermoelectric techniques. ★

NEW METEOROLOGICAL-ROCKET SYSTEM

AEROSPACE INSTRUMENTATION LABORATORY, AFCRL

A new miniaturized meteorological-rocket sounding system has been successfully demonstrated by AFCRL. The two-element LOKI-Dart system offers marked advantages in cost, size, handling capability, and performance over meteorological rockets used widely in the past.

Although LOKI-Dart systems have been used previously in rocket meteorology, their uses were confined to the release of chaff in the upper atmosphere for radar tracking. The distinctive aspect of the AFCRL development is in the design of rugged, miniaturized instrumentation that can fit into the 1.375-inch diameter Dart and withstand the rocket's 200-g acceleration.

The 8.5-pound upper-stage Dart carries a 1.5-pound pay load to approximately 200,000 feet. At that altitude, the pay load is ejected and descends by parachute. As it descends, it telemeters temperature data to a ground station. Radar tracking of the metalized parachute provides altitude and wind information.

The rocket booster of the system is of the LOKI class, originally developed as an anti-aircraft rocket. The booster is three inches in diameter, and has a center-burning solid-fuel motor. The rocket burns for only about two seconds. At the end of that period, at roughly one-mile altitude, the booster drops off and the upper-stage unpowered Dart carries the pay load to the 200,000-foot altitude.

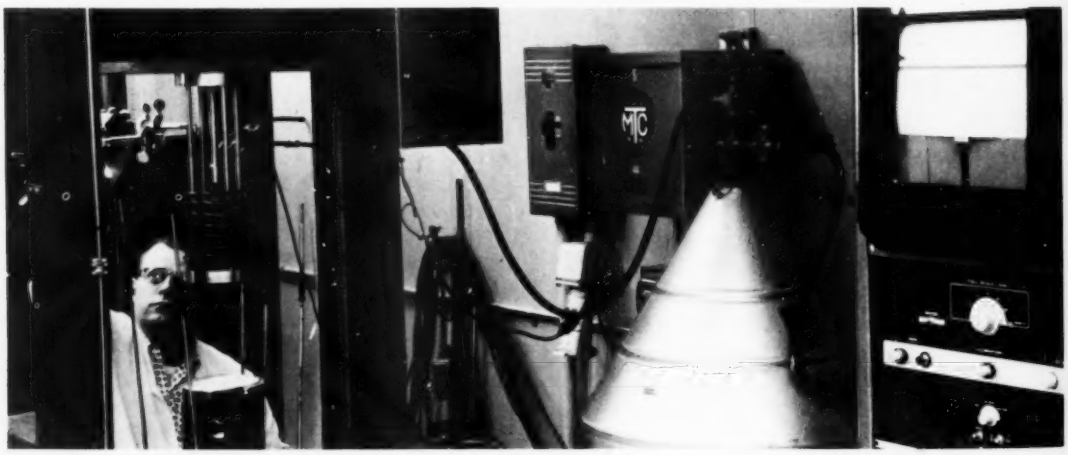
The complete system weighs only 32 pounds. Over-all length is about 9 feet, of which the LOKI comprises 66 inches and the Dart 45.5 inches. It obtains a maximum velocity of 5,000 feet per second.

One of the important features is that the system is less wind-sensitive than previous meteorological rockets and can be fired in winds up to 30 knots. (Slower accelerating rockets tend to weather vane in high winds.) Of primary importance is that the miniaturized system provides essentially the same data obtained with much larger meteorological-rocket systems and at less than half the cost. The new system also requires a minimum of handling effort by the weather-station launch crew.

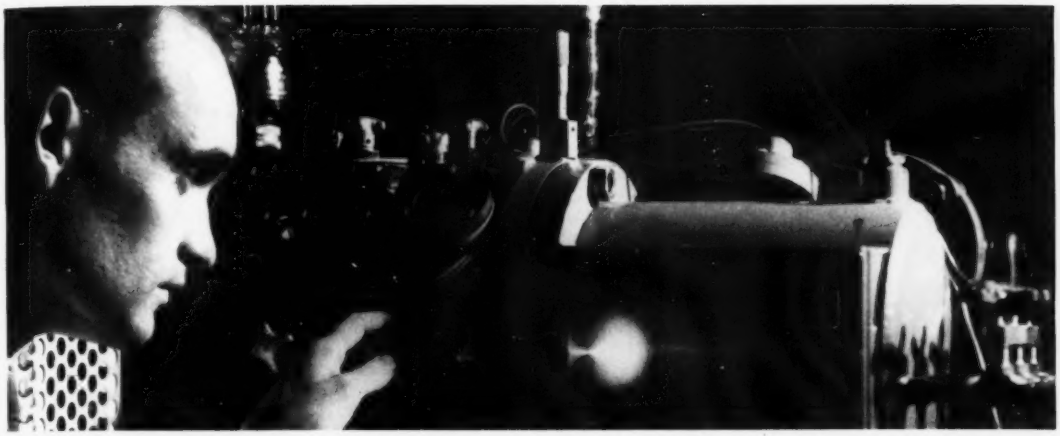
Six test launches have been made by AFCRL at the White Sands Missile Range, and 10 at Cape Kennedy. The Dart system was designed for AFCRL by the Space Data Corporation of Phoenix, Arizona. The telemetry package was designed by Metro-Physics, Inc., of Santa Barbara, California. The AFCRL program was directed by Robert Leviton with the assistance of Konstantins Pocs. LOKI-IIA motors manufactured by the Marquardt Corporation were used in the test flights. ★

a cross section of
OAR RESEARCH ACTIVITY

S/Sgt. David Stewart of the Data Sciences Laboratory, AFCRL, at the microscope looking at a Golgi-stained section of a rat's cerebral cortex with closed circuit TV displaying the slide magnified 2,000 times. Cells in the visual area of the cerebral cortex are involved in the processing of visual information in the rat's brain. In the Laboratory, measurements are recorded of the electrical activity of that portion of the rat's brain. This is part of the research in visual information processing.

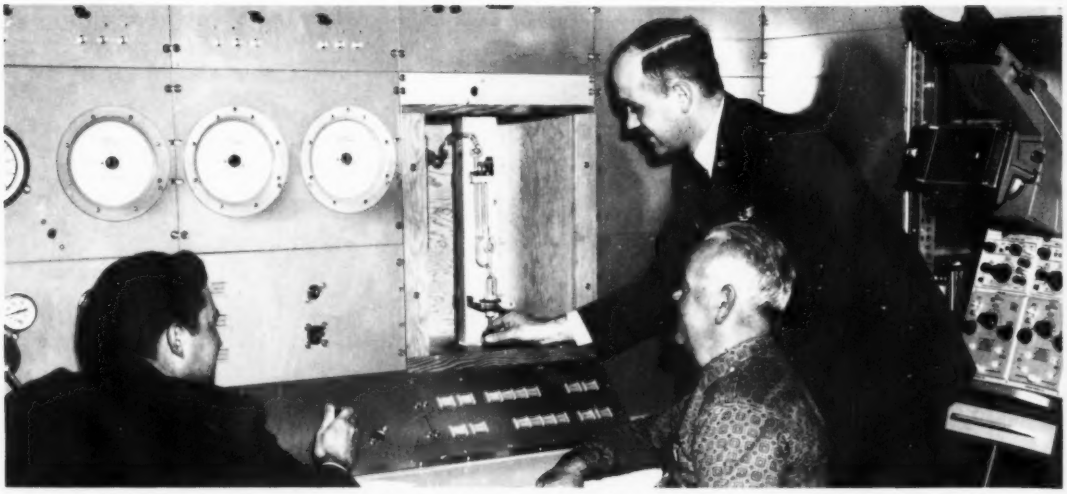


Research efforts under the direction of Mr. Edward J. Hassell, Metallurgy and Ceramics Research Laboratory, ARL, include use of the Enstron testing machine in the study of flow and fracture characteristics over wide temperature ranges.



Shown here is Mr. Robert O'Neil, contractor with the Optical Physics Laboratory, AFCRL, at an apparatus employed for electron bombardment of atmospheric gases. The particular reaction seen here is the bombardment of nitrogen by 50-KEV electrons at about 2 millibars of pressure.

Lt. Colonel John T. A. Ely, of the Space Physics Laboratory, AFCRL, testing circuits of an instrument pay load flown to more than 100 thousand feet aboard high-altitude balloons in a series of cosmic-ray studies. Instrumentation and emulsion packs (as well as laboratory animals) have been integrated into pay-load spheres of the type shown in the left portion of the photograph. Col. Ely conceived the cosmic-ray experiments undertaken for measuring the energies, rate of occurrence, and direction of cosmic rays at high altitudes.



L to R: Captain Douglas S. Johnson, Mr. George Schimmack and 1/Lt. Charles F. Stebbins, at Frank J. Seiler Research Laboratory, USAF Academy, Colorado. Captain Johnson injects test gas into the test section of the FJSRL shock tube from the instrument console as Lt. Stebbins and Mr. Schimmack measure the pressure with a McLeod gauge.

Dr. Glen R. Buell, a research chemist with the Chemistry Research Laboratory, ARL, is shown checking out his experimental equipment for studying the absorption of hydrogen by organosilicon compounds at elevated temperatures and pressures.

strategy for attacking the THREE-BODY PROBLEM

SOLID STATE SCIENCES LABORATORY, AFCRL

An improved method for dealing with one of the most challenging of all mathematical problems--the three-body problem--has been devised by Dr. Leonard Eyges of AFCRL. The problem is that of describing mathematically how three bodies, each exerting a force on the other two which depends on the relative distance between them, behave with respect to each other. Although the more familiar instances in which this problem crops up--such as the behavior of asteroids under the gravitational influence of both Jupiter and the Sun--lie in the realm of celestial mechanics, the three bodies involved do not necessarily have to be celestial. They may be atomic or subatomic particles, and the forces between them need not be gravitational. They may be electromagnetic or nuclear. It is with the latter type of three-body problem that Dr. Eyges' method deals.

Since modern atomic theory and quantum mechanics are inextricably related, the behavior of three interacting atomic or subatomic particles becomes a quantum-mechanical three-body problem. At first glance, it might seem that such a problem would be more difficult than the three-body problem of classical or Newtonian physics; but this is not the case. Quantum theory allows particles to have only certain discrete energies, and this condition imposes a limitation on their behavior. Actually, if all their possible energy states are considered, the problem becomes identical with the three-body problem of classical physics. But if particles in only a single energy state are considered, the problem is greatly simplified, although still complex.

The reason that the quantum-mechanical problem remains complicated, even though only a single energy state is involved, is the fact that the Schroedinger equation, which relates the forces, masses, and positions of the particles, requires nine variables (three per particle) to completely describe three interacting particles. By a standard mathematical trick, involving a center of mass transformation, the number of variables in the equation can be reduced to six. But even after this is done, there are still too many variables for the problem to be solved with mathematical exactness, and approximations and simplifying assumptions must be made. In general, the problem can only be solved for special cases.

The case which Dr. Eyges selected to study is that of three particles of equal mass, each having an attractive field. Although this situation does not actually occur in nature, the significance of Dr. Eyges' achievement lies more in the novel mathematical treatment which he gives the problem, than in its relevance to actual situations in nuclear or atomic physics. (It does bear some similarity to the problem of the behavior of the two protons and one neutron in the nucleus of the Helium 3 isotope. Solutions of this case of the quantum-mechanical, three-body problem may also be used to calculate the statistical properties of gases where three-body interactions among gas molecules are frequent.) The treatment may be extended to other quantum-mechanical situations. Essentially, this treatment consists in writing the Schroedinger wave equation in such a way that, through a series of transformations and approximations, it can be put into a form similar to that of the two-body problem. Two-body problems are relatively easy to solve.

One distant (and perhaps unattainable) goal of quantum-mechanical three-body studies, such as that made by Dr. Eyges, is the prediction of the physical properties of new materials and alloys. This actually involves a many-body problem, the many bodies, as an example, being the atoms in a crystal lattice. The three-body problem is only one special case of this many-body problem; but extending three-body solutions to problems involving more than three bodies will probably be easier than finding the solutions originally. ★

PROFILES

Mr. Theodore E. Wirtanen (left) and Mr. Robert L. Iliff (right) are both with the Geodesy Branch, Terrestrial Sciences Laboratory, AFCRL, Mr. Wirtanen as a geodesist, and Mr. Iliff as a research physicist. Mr. Wirtanen has been with AFCRL since 1959. He is presently engaged in research into new techniques for combining speed, mobility, and accuracy in developing geodetic and selenodetic positions. He received a B.A. in History cum laude from the University of New Hampshire (1951), and successfully completed a course in Advanced Cartography (1954) and one in Advanced Geodesy (1956), both at the Army Map Service Training School. Mr. Wirtanen has several papers and inventions to his credit. Mr. Iliff is currently doing theoretical and experimental work with high-energy lasers as a geodetic tool. He completed one year of engineering at the University of Nebraska before being called into the service. Subsequently, he received a B.A. in Physics and Astronomy from Boston University (1961). Mr. Iliff has worked previously at the Artic Institute of North America, Washington, D.C., and in private industry. He has several papers to his credit. The article, "Laser Beam Bounced from Satellite," which appeared in the April 1965 issue of the Review, describes a recent experiment by these two AFCRL scientists.

Lt. Col. Morris C. Burkhart, an ARL scientist with the Fluid Dynamics Facilities Laboratory, came to the Aerospace Research Laboratories in January 1965 from Oklahoma State University. He had been at that university since 1960 where he received his B.S. (1962), M.S. (1963), and Ph.D (1965) degrees in Mechanical Engineering through the Air Force Institute of Technology program. During World War II, Lt. Col. Burkhart flew 96 combat missions as a fighter-bomber pilot in the European Theater of Operations, and was credited with shooting down one ME-109. Later, during the Korean War, he served as an intelligence officer in Japan. Lt. Col. Burkhart wears the Air Medal with 13 Oak Leaf Clusters, the Air Force Commendation Medal, the Korea Service Medal and other decorations. He is a member of PHI KAPPA PHI, National Scholastic Honorary Society, and PI TAU SIGMA, National Mechanical Engineering Honorary Society. In this issue of the Review, Lt. Col. Burkhart writes on "Electrical Contact Response in a Vibratory Environment."

Mr. Paul W. Schreiber, an ARL scientist with the Thermomechanics Research Laboratory, is currently doing research concerned with the application of experimental and theoretical plasma physics to electric arcs. This work includes developing experimental and analytical techniques to determine the special distributions of emitted radiation, absorbed radiation, temperature electron density, and ion density in alternating-current and direct-current arcs as a function of time. Mr. Schreiber has a B.S. from the University of Dayton (1950) and an M.S. from Ohio State University (1956). He has also completed 40 semester hours beyond the M.S. degree at the University of Cincinnati. He has a number of publications to his credit. In the May 1965 issue of the Review, he wrote on "Radiation from an Alternating-Current Nitrogen Arc."

Mr. George S. McLean, Jr., at the Aerospace Instrumentation Laboratory, AFCRL, has, since November 1963, been Project Scientist for the Atmospheric Sensing Techniques Project. In this capacity, he has coordinated the development of direct and indirect sensing equipments and techniques. Also, as a research meteorologist, he has conducted independent studies in order to determine parameters upon which to base future sensing-equipment developments. Mr. McLean attended Northeastern University in 1942 prior to entering military service. From 1953-1958, he attended Boston University and M.I.T. as a special student, taking undergraduate and graduate courses in Mathematics and Meteorology. The article, "CAT (Clear Air Turbulence): Finding a Suitable Bell," which appeared in the April 1965 issue of the Review, describes some of his work.

Mr. Henry E. Fettis, an ARL scientist with the Mathematics Research Laboratory, is currently doing research in mathematical physics, and investigating the application of rational approximations to transcendental functions as a means of obtaining numerical values for inverse Laplace transforms. He has a B.A. degree from Wittenberg College (1939), and an M.S. from Ohio State University (1952). Mr. Fettis also attended Stanford University from 1960-1961 under an NSF fellowship. He has a great number of publications to his credit. In this issue of the Review, Mr. Fettis writes on "The Conversion of a Power Series to a Continued Fraction, or How to Get Something for (Practically) Nothing."

ORIGINS OF MAGNETIC FLUCTUATIONS

SPACE PHYSICS LABORATORY, AFCRL

Until about 5 years ago, natural magnetic fluctuations in the 1 to 45 cps region were something of a mystery. Questions focused on whether they were of terrestrial or extra-terrestrial origin. Recent measurements by a number of researchers have provided strong evidence to support the view of terrestrial origin.

Elwood Maple of AFCRL has recently completed a thoroughgoing analysis that goes far toward eliminating any residual mystery concerning the origins of magnetic fluctuations. It now appears that they originate largely in thunderstorm activity. The study was based on magnetometer data taken over a six-months' interval--July through December 1964--at Denver, Colorado. Diurnal and seasonal variations in the intensity of these fluctuations correlate quite directly with world-wide thunderstorm activity.

Measurements were made of fluctuations over a range of from 1 to 45 cps in 6 octave frequency bands. Three components of the magnetic field--north-south, east-west, and vertical--were measured. Previously, other scientists had suggested the following model for the magnetic fluctuations, a model supported by the extensive AFCRL observations: A resonance is set up in the natural waveguide cavity between the earth and the ionosphere. This cavity resonates as a result of interaction with the electromagnetic energy generated by lightning strokes. The earth-ionosphere cavity thus modifies the spectrum radiated by the source. Furthermore, as with any spherically symmetrical wave guide, resonances occur at several resonance modes, the lowest being at about 8 cps.

About 50,000 thunderstorms occur each day throughout the world, and about 100 lightning discharges occur each second. This means that, essentially, the source is a continuous one. Thunderstorm activities vary seasonally and diurnally. In comparing the Denver magnetometer data with the expected effects of thunderstorm activity, variations in both the distance and direction of the thunderstorm-activity source from the Denver site were key considerations.

It is clear from a comparison of the daily plots of amplitude fluctuations of the six frequency bands monitored that almost all of the magnetic fluctuations originate from a common source. The data taken at the Denver site strongly correlates with thunderstorm activity associated with the large land masses of the world. Thunderstorm activity reaches a maximum in midafternoon, tapering off in the evening, and arriving at a minimum in the morning hours. The intensity of the magnetic fluctuations follows a similar pattern. The three major thunderstorm centers of the world, of course, reach their peaks of activity at different times.

Because the amplitudes of the fluctuations are greatest when heavy thunderstorm activity is located nearest the detection site, one whould expect the Denver sensors to detect the most pronounced fluctuations in the afternoons of the summer months. This was in fact the case.

The amplitudes of the fluctuations were strongest at a frequency of about 1.5 cps (the lowest of the 6 octave frequency bands observed) when the thunderstorm activity was within about 2,000 miles of the receiving site. For more distant activity, the amplitudes at frequencies corresponding to the resonant modes of the earth-ionosphere cavity become predominant.

Although thunderstorm activity does account for most of the data, it does not account for all of it. Some contributions are made by geomagnetic sources, particularly contributions in the frequency regions of 1.5 to 2.6 cps. Such contributions, arising from magnetospheric sources, are most pronounced at night and during the winter months when thunderstorm contributions as observed at Denver are at a minimum.

POSTMORTEMS CAN BE Fun the cost analysis of information systems

DR. HAROLD WOOSTER, Directorate of Information Sciences, AFOSR

This paper summarizes three doctoral dissertations from the Graduate School of Library Services of Rutgers University. These were funded by the Directorate of Information Sciences, Air Force Office of Scientific Research, OAR as part of its dialectic approach to the problems of information handling. The studies were carried out under the supervision of Ralph Shaw, Dean of the above mentioned Graduate School, and bear one of the Shaw trademarks--a meticulous analysis of unit costs of operations. This is not glamorous; it might even be called dull, so long as someone else's ox is being gored.

A cynic is defined as one who knows the price of everything and the value of nothing. Many concerned with the evaluation of information systems would like to be cynics, but can't get enough information on prices to make a beginning.

What sort of facts came out of this research program?

Photocopies as panaceas

It is not infrequent for those concerned with The Library Problem or The Journal Crisis to suggest that libraries subscribe to, keep and bind only a small core collection of hard working journals; photocopies of articles in wallflower journals would be requested on an ad hoc, individual basis. This suggestion has met the customary mingled reception from librarians, and almost mass revulsion from publishers of scientific journals. Dr. Robert Clarke, now with the National Library of Medicine, undertook an investigation of the impact of photocopying upon scholarly publication and on libraries.

Dr. Clarke's dissertation started with an examination of records of journal photocopying at three major library photocopying services, and found only an average of 6.1 articles copied per journal copied. I would have predicted that the actual journals copied from would bear some sort of inverse relationship to their popularity--that the rarer journals would be those the libraries would be less likely to have, and that therefore such journals would be copied more frequently. In fact, the relationship seems to be direct--it is not the rare journals but the readily available journals that are photocopied.

When is it cheaper to photocopy specific articles or to buy and keep a journal? It costs about $2 to get a paper photocopy; over a 20-year period, even a journal like the $45-a-year Journal of Biological Chemistry costs less than $3 a year to own. If two articles per year are called for, it is cheaper to own. Clarke suggests that "Libraries should. . . . subscribe to journals with subscription prices of $30 or less if one year volumes are needed an average of once per year over a 20-year period or longer."

The numbers in this rule, however, should not become a permanent part of the Lore of the Librarian. Journal and storage costs are bound to go up--the mechanical costs of photocopying to go down. I do not foresee any change in the pattern of requests for photocopies of journals. I doubt that any technological revolution is going to make the wallflowers popular.

Three systems of information retrieval

One of the standard distinctions being made these days is between "fact" and "document" retrieval. Norman Stevens studied one such fact-retrieval operation--a punched-card compilation of the properties of ex-

plosives made by Arthur D. Little for Picatinny Arsenal. Stevens' dissertation was summarized in American Documentation, 12, 243-246, 1961. Little labored from 1954 through 1961. The final product was a set of 80,000 cards, covering 6,200 compounds and 1,814 mixtures, based on data extracted from either 3,420 references or 900 reports.

The set, or 68 subsets, of cards could be used either for subsequent machine-sorting or as an ordinary manual card catalog. Eleven such sets of cards were made and distributed to various installations. The cards were also printed out into a handbook of which 74 copies were distributed.

As a control, Dr. Stevens used the Picatinny Arsenal technical library, with its 125,000 technical reports, 18,000 books and 850 technical journals. The technical reports have a Uniterm catalog of their own, plus a conventional subject catalog.

Input costs for the punched-card system were about $250 per report, when the annual costs of operation are divided by the number of reports processed. This amounted to about $70 per reference, or $3 per separate card.

The Picatinny Arsenal library estimated that their costs in 1956 for accessioning and Uniterm cataloging reports was 70¢ per report, in contrast to the data-extracting system's costs of $70 per reference or $250 per report--a difference of 106 times as much per reference, or about 362 times as much per report. Also, the punch-card file seemed to show an average delay of 4 months in processing time.

It can, of course, be argued that the additional expense and delay of input to the punched-card system are more than balanced by the difference in favor of the mechanized data-handling system in output costs and times. This was the next assumption to be checked.

Information was obtained about the use of 9 of the 11 sets of punch cards distributed. Six of the 9 sets had never been used at all--largely because of the problems involved in getting access to card-sorting equipment, even though it was on the premises in the iron clutches of the Comptroller.

Three sets of cards are known to have been used, perhaps four or five times in all. The greatest use of the cards was made at Picatinny Arsenal, where it was possible to identify 22 questions that had been asked in the last 7 years. If one estimates that, at most, 50 questions will be asked before the cards grow obsolete, and ignores the use of the handbook, the cost per machine question, if only that file existed, would be $5,000. One could do a fair amount of ordinary literature searching for that amount.

We mustn't forget, though, that 73 copies of the printout were distributed to 27 installations. Various supplementary sheets had been issued to keep the handbooks up to date; only 5 copies had the inserts filed according to directions and, in a number of cases, including one copy that was receiving intensive use, the supplements had never gotten to the holders of the main issue.

Three potential users said that they'd never heard of the handbook, even though the library charge sheets (and this was a Confidential document) showed that they'd borrowed it.

It was possible to identify, for the 15 copies of the handbook receiving most frequent use, something like 8 uses in a 2-month period. Putting everything in the most favorable light--all 75 copies used at the same rate since the handbook was issued, which was certainly not the case--this would make some 2,400 uses over a 10-year period. Even adding in the uses of the card file, this would not make over 2,500 uses, or a total of $100 per use.

As Stevens points out:

"Here there is a situation, which is undoubtedly not atypical of mechanized systems of information retrieval, in which a large amount of money has been expended on a highly specialized tool that by its very nature does not, and probably should not be expected to, receive frequent use, and which tends to become obsolete very quickly. On the other hand, with the alternative, but much more limited approach of the card catalog, traditionally as little money as possible is expended for a highly diversified tool that is heavily used for a long period of time.

Surely here the relative values of the two approaches are sadly out of focus."

The Life and Death of an Information Center

It would seem to be profitable, in this brave new world, to examine an "Information Center That Was." This Richard Dougherty did in his study of the Chemical-Biological Coordination Center. CBCC operated under the aegis of the National Research Council between 1 July 1946 and 1957. (Coll. Res. Libraries 20, 7-12, 1964) In its 9 years of existence, CBCC coded and abstracted a total of 218,000 biological responses to 63,000 chemical compounds. These data were stored on approximately 1.5 million prefiled punch cards. Eighty per cent of the files consisted of data coded from some 50 scientific journals--the rest came from the screening program or other unpublished sources. As of August 1962, these files and their attendant code sheets were neatly piled in a laboratory in Walter Reed where radioactive isotopes were being tested!

Over $1.5 million dollars were appropriated in support of the center during its existence, with the annual income never exceeding $200,000, averaging about $175,000, declining in the latter years of its life.

There are many good things to be said about CBCC. It pioneered in showing what could, and couldn't be done with punch cards in handling large amounts of chemical and biological data. It developed the NRC Chemistry Code and the Biology Code. Many of the technical problems it struggled with could be easily handled with today's computers. Perhaps, most important of all, it served as an existence (or nonexistence) proof of the biogeopolitical problems of information centers.

In its 11 years of existence, CBCC processed over 1,300 information requests. Of these it was able to satisfy 30 per cent, partially satisfy 25 per cent, and unable to answer 45 per cent. One of the primary reasons for using punched cards was the putative ability to correlate biological and chemical data. But, so far as it can be ascertained, although 47 requests were submitted, no correlation study was ever performed by the Center in response to a question submitted by a scientist.

The Center's input procedures were excellent, if complicated. Some idea of the complexity may be gained from the training times required--from two to three months to train a coder, from two to three years to train a qualified chemist to name compounds according to the Chemical Abstract system of nomenclature, and at least three months to train professionally qualified biologists before they became fully productive.

As a result, input costs were high. The cost of collecting and processing data from the literature was estimated at $3.67 a line; the calculated unit cost per line from the screening program came out to $6.66.

Costs of answering questions were correspondingly high. The Center estimated the cost of answering requests as somewhere between $60 and $160. For one sample of 1,000 requests, however, they were only able to successfully answer some 30 per cent, and only 30 per cent of these were answered from data from the Center's files. On this basis, the input cost per request was about $1873!

With 20-20 hindsight, it might be said that CBCC's failures fell into four categories. They had not been able to demonstrate that their services were unique, especially when they answered questions from the open literature, rather than their own files. They had not been able to develop an integrated storage and retrieval system. They had been so busy developing an ability to code and store data that the retrieval portion of the system had been neglected. In all probability, they spread themselves too thin--it would have taken an annual budget of $1 million a year to do everything they wanted to do. By trying to do everything, they did nothing well. And, whether as a result or a cause of the first three, they were never able to attract adequate and stable financial support--in spite, or perhaps because of, receiving sponsorship from five different agencies. It would seem that the requirements for an information center head in these decadent

days are about the same as for a college president--it is nice if he is a scholar, but he must be a successful fund raiser.

One would hope that the head of an information center would recognize that, even though, as all scientists (and almost no nonscientists) know, scientists can do anything and everything, it actually takes four different sorts of skills to man an information center: subject specialization, bibliographic competence, knowledge in depth of the devices and mechanisms available to do bibliographic operations, and administrative ability. ★

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"WHODUNIT" (the nature of complex ions)

DR. AMOS G. HORNEY, Directorate of Chemical Sciences, AFOSR

The "Whodunits" are absorbing reading for many people. The mysteries of who, how, and why in chemistry are about the species which undergo reaction or cause chemical reactions. The understanding of who, how, and why requires an accurate knowledge of the nature and structure of chemical species. For example, X-ray and other diffraction techniques are used to give an accurate picture of the detailed structure of ionic solids. These techniques are not so useful in providing information about the nature of the same species when these substances are dissolved in water or in aqueous saline media.

Surprisingly enough, such common ions as sulphate and phosphate still present real problems, particularly from the point of view of internal electronic structure, even though they have been known and studied for decades.

A phase of the researches of Prof. Robert Plane of Cornell University, under AFOSR sponsorship, has resulted in elucidating the structure and nature of a number of important species in relatively concentrated aqueous solutions. He employed Raman spectroscopy, isotope tracer studies and other techniques to attain the results.

A major part of the total effort was the investigation of complex ions by the use of this Raman spectroscopy. This technique, which had not previously been used to any appreciable extent in such studies, proved to be eminently suitable for detecting the presence of associated species in solution, determining their structures, and disclosing the mechanism of bonding operative in the various species.

The systems investigated included nearly all colorless metal ions (with particular emphasis on the posttransition metals Zn^{++}, Cd^{++}, Hg^{++}, Ga^{+3}) in combination with halides, cyanides, nitrates, perchlorates, sulfates, oxalates, acetylacetonates, ammonia, and methylamine. Thermodynamic data, i.e., equilibrium constants, enthalpy and entropy of association, were obtained for calcium-nitrate solutions and the bromides of zinc, cadmium, and gallium. These results were of key importance in assessing reasons for ion association and reasons for the formation of more than one complex species in certain systems. It was shown, furthermore, that while nitrate ions quite generally associate directly to metal ions, direct association of ClO_4^- and $SO_4^=$ is rare. Only in the case of

In^{+3} and $SO_4^{=}$ is direct association observed. In all other cases studied, any association which occurs is of an indirect nature as by electrostatic attraction between anion and hydrated cation. In such solutions, the Raman spectra of the hydrated cations were measured for the first time.

An important result of the Raman studies was the interpretation of the intensities of Raman lines in terms of bond type within the molecule giving rise to the spectrum. Thus it was shown that multiple bonds give rise to correspondingly more intense spectra than do single covalent bonds, and that partial bonds give rise to correspondingly less intense spectra. Using this criterion, it was established that, within complex species, all atoms maintain charges of less than one unit from electrical neutrality either by forming, in most cases, partial sigma bonds or, in a few cases, by back donation to form multiple bonds. The extent of covalent bond formation was found to be a function of the base strength of the ligand. More detailed correlations were not allowed due to results which proved, for the first time, that Raman intensity is a function of the atomic polarizabilities of the atoms connected by a bond. However, pathways were opened for future studies which should allow further interpretation of the results obtained.

Among the problems related to an understanding of solute species, perhaps none has proved more difficult than that of showing definitely whether or not species form which contain more than one cation. During this project, definitive evidence was obtained for two different systems. For one of these, hydrolyzed Cr^{+3}, a complete formulation of a polymerized species was obtained. Through the use of ion-exchange studies coupled with oxygen isotope experiments, the species was proven to be $Cr_2(OH)_2(H_2O)_4^{+4}$. Not only was this the first such species completely formulated, but data were obtained which indicated the mechanism for its formation from Cr^{++} and O_2. The other system studied involved Co(III) copolymerized with periodate. The polymer consists of 4 Co and 3 I atoms each octahedrally surrounded by oxygen atoms. Although it could not be completely characterized, this research opened up a new field of study which is being actively pursued in other laboratories.

From Raman studies, it was shown that ions of +2 or higher charge exist in solution covalently bound to H_2O molecules forming discrete molecular species. The existence of Raman spectra proved that the hydrated cations retained identity for periods of time long compared to vibrational times (10^{-13} sec). Experiments using oxygen isotopes to measure actual lifetimes of such species showed that, except for certain solutions containing Fe^{+3}, lifetimes are much shorter than 10^{-3} sec.

The interpretation of the lack of Raman spectra for sulfate and perchlorate solutions of multiply charged ions raised the possibility that, in such solutions, association occurs not directly between cation and anion but through an intervening solvent molecule--a water of hydration of the cation. Such species have been identified by ultraviolet spectroscopy, but previous results disagreed violently as to the quantitative extent of such association. To resolve the difficulty, experiments were performed in an unambiguous model system (trisethylene-diammineplatinum IV plus various cations) which showed that many previous workers had overestimated the importance of such association, and specifically that, whereas outer-sphere association is quite important for sulfate solutions, it is much less so for univalent anions, and particularly of no detectable importance for perchlorate ions.

While it is patently impossible to predict the future impact of any given piece of basic research, it appears that the results of this study will be important in such diverse areas as the understanding of the mechanisms of oxidation and corrosion reactions, energy transport in fluid media, and improved concepts of bonding in simple and complex solids. ★

TO OUR READERS

Requests for further information should be directed to the individual or laboratory of origin (except for those from Latin America).

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